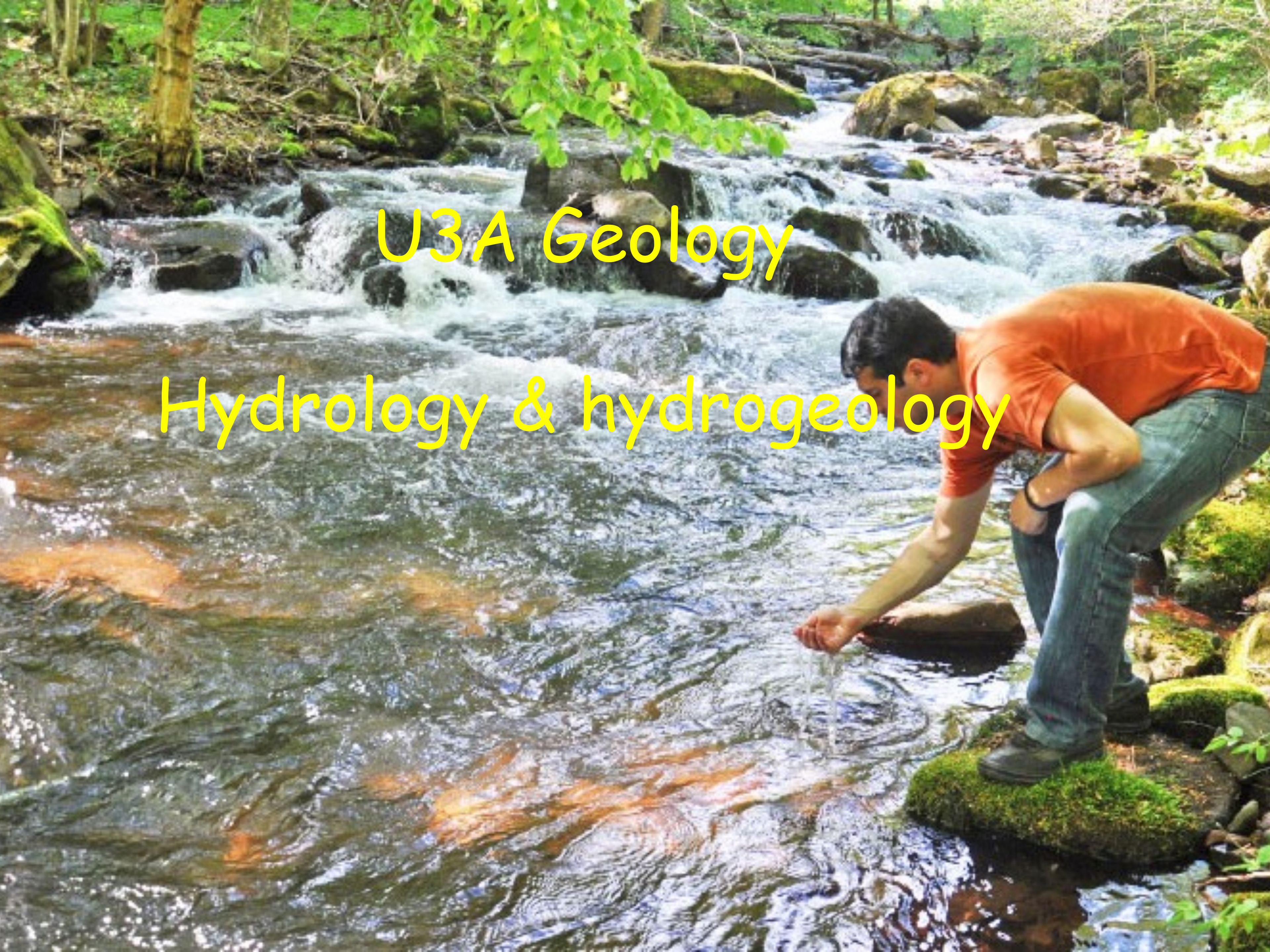

U3A Geology
Hydrology & hydrogeology

Hydrology & hydrogeology

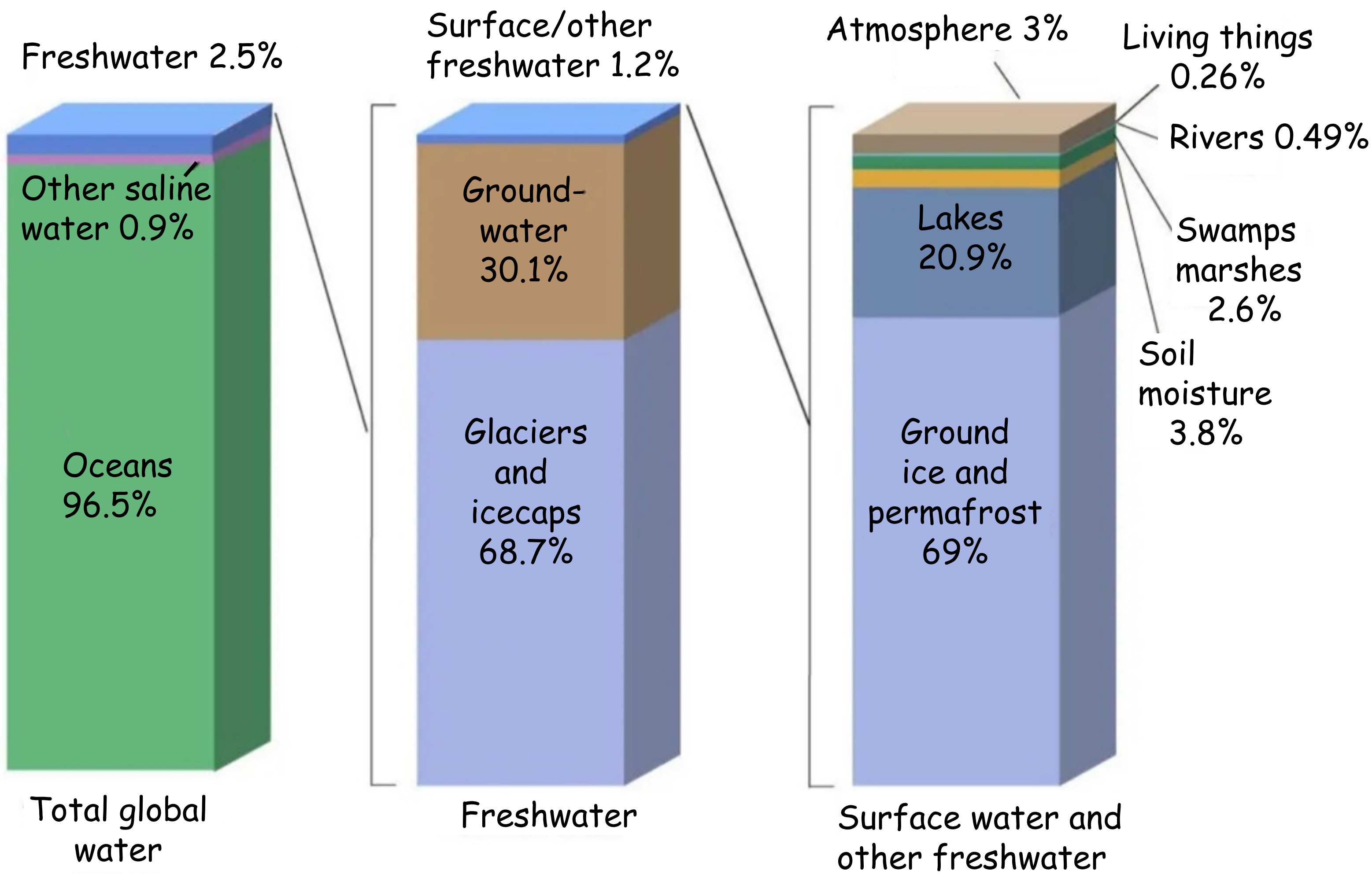
Hydrology is the study of the distribution and movement of waters both on and below the Earth's surface and their interaction with the physical and biological environment

Hydrogeology is the study of groundwater including recharge and subterranean flow through aquifers and other porous media

Water budget

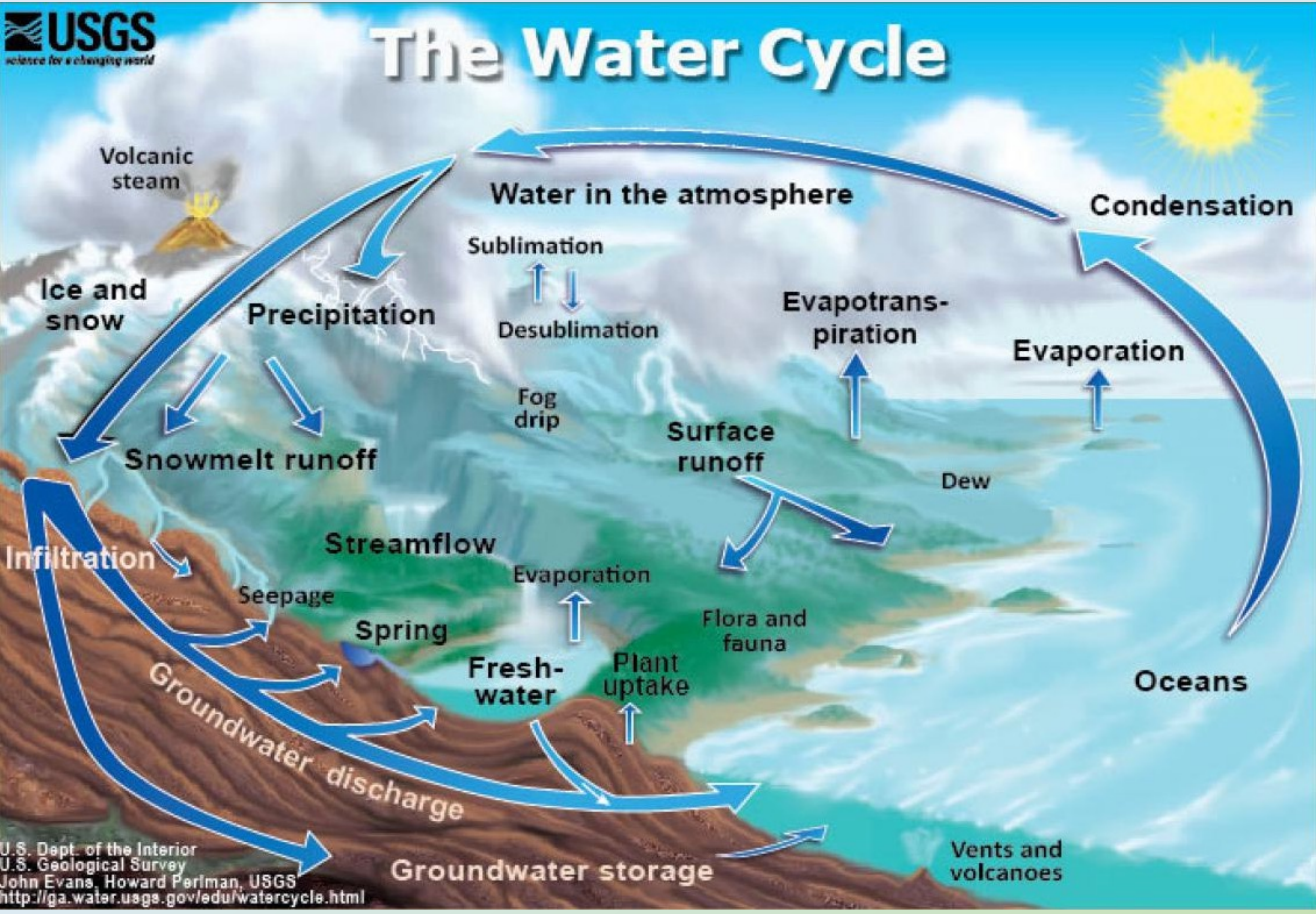
- About 71% of the Earth is covered by water
- oceans hold about 96.5% of the Earth's water
- water also exists in air as water vapour, in rivers, lakes, icecaps and glaciers, in the ground soil as moisture and aquifers
- only about 1.2% of freshwater is surface water
- most of surface freshwater is locked up in ice (~69%) and another 20.9% in lakes
- rivers only make up 0.49% of surface freshwater

Water budget



The water cycle

- All of the water in the hydrosphere is caught up in the water cycle
- world's largest reservoir → ocean → contains 96.5% of water in the hydrosphere. Lakes and streams only 0.016%
- the main processes of the water cycle involve evaporation into and precipitation out of the atmosphere
- precipitation can runoff land surface or infiltrate underground
- total water moving through the water cycle >400million billion litres/year
- water in hydrosphere can spend extended periods (even 10s of thousands of years) in one or another of the reservoirs


USGS
science for a changing world
The Water Cycle
Volcanic steam
Water in the atmosphere
Condensation
Sublimation
Desublimation
Ice and snow
Precipitation
Evapotrans-piration
Evaporation
Fog drip
Surface runoff
Snowmelt runoff
Dew
Streamflow
Infiltration
Evaporation
Seepage
Flora and fauna
Spring
Fresh-water
Plant uptake
Oceans
Groundwater discharge
Vents and volcanoes
Groundwater storage
U.S. Dept. of the Interior
U.S. Geological Survey
John Evans, Howard Perlman, USGS
http://ga.water.usgs.gov/edu/watercycle.html

Occurrence of water

- Free water comprises about 0.2% of the Earth's mass
- all naturally occurring water is a constituent of the water cycle involving a closed loop of movement between the solid Earth, seas and atmosphere
- sometimes water movement is fast (e.g. torrential rain) but it is more commonly slow moving
- man makes intensive use of a relatively small fraction of the water cycle → surface water in streams and lakes with underground water to a depth of ~400m

Movement of water

- In order for the water cycle to function, water must change its state at various times
- it may be frozen in snow and ice or vaporised in hot springs and geysers. Water in the atmosphere results mainly from evaporation or evapotranspiration
- water percolates down through the soil under influence of gravity
- water absorbed by soils → available for uptake of plants or lost through evaporation
- at some depth, soil gives way to rocks. Soil discontinuity may induce water into a water course or more permeable rock layer

Movement of water

- Bulk of infiltration will continue downwards
- between the ground surface and level of saturation there are 3 distinct zones:

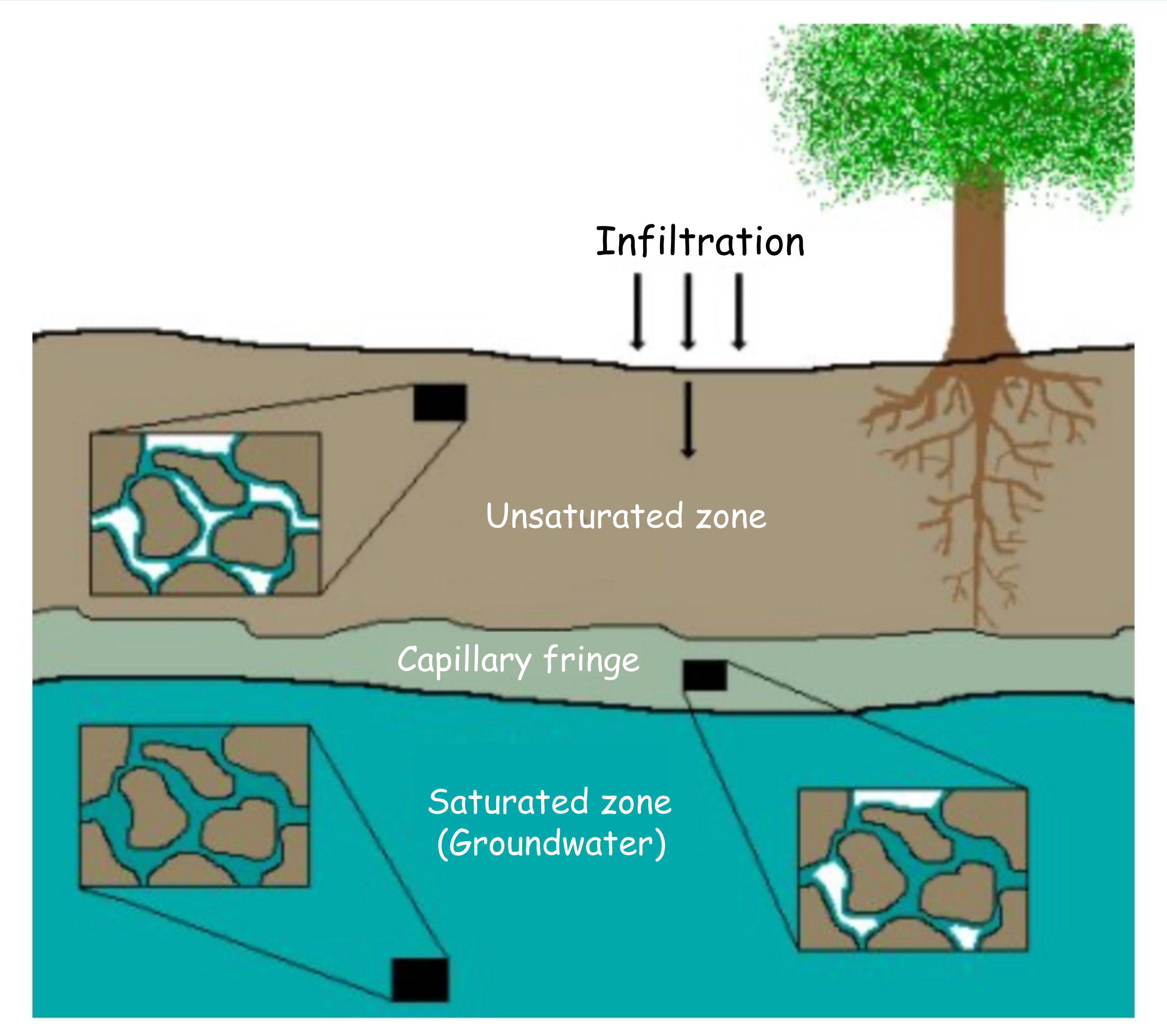
  (1) unsaturated (phreatic) zone → pores are never completely filled → water migrates → some retained in pore space

  (2) zone of intermittent saturation → from highest level of saturation zone to lowest level

  (3) saturated → pores and fissures permanently filled with water

- boundaries are clearcut. There is a capillary fringe above saturated zone where pores are partly filled by capillary action

Zonation of underground water



Sub-surface water

- If soil on which precipitation falls → sufficiently permeable → infiltration occurs
- gravity draws water downwards until impermeable soil layer is reached → water basins accumulate above it
- immediately above the impermeable layer → zone of rock or soil that is water saturated
- above that → rock or soil partly filled with water, partly with air → aeration or vadose zone
- true groundwater is water in zone of saturation only

Groundwater

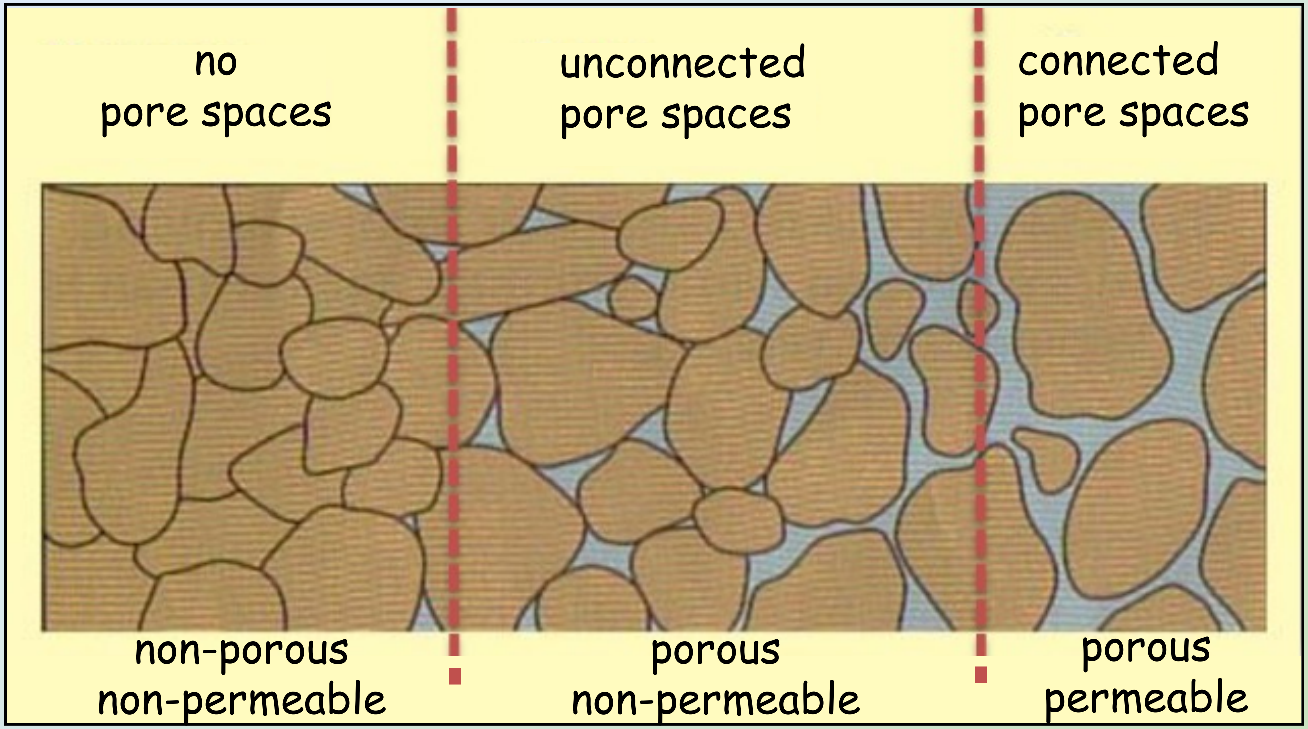
- Groundwater → fresh water located in sub-surface pore spaces of soils and rocks and fractures in rock formations
- groundwater normally considered as water flowing through a rock layer or unconsolidated deposit called an aquifer
- about 30% of readily available freshwater in the world is groundwater
- groundwater most accessed water in the world → used for drinking water, irrigation and industrial purposes
- groundwater quality is highly variable → may be nearly as pure as rainwater or saltier than ocean water

Porosity vs permeability

- Porosity – spaces within material that contain fluid
  - primary if formed at the same time as soil/rock material
  - secondary if formed later than rock

- Permeability – size and degree of connection of pore spaces.

  Ability of a fluid to pass through a material



Porosity in the regolith

Porosity → ratio of pore volume to volume of rock

perfectly packed rounded sandstone	→ ~25%
loose gravel and sand	→ ~35%
cemented sandstones	→ 5-15%
poorly consolidated clay may be high	→ ~40-50%
compacted clay (shales, slates)	→ ~3%

Transmission of groundwater

- Rock formations that both store and transmit water are called aquifers
- these include most sandstone formations, limestone and chalk
- fissure flow → significant as means of rapid water transmission
- degree of interaction between water stored in pores and fissures and intergranular flow control geochemical processes → determine groundwater quality
- formations that cannot store water are called aquicludes → these include fine-grained clayey rocks and many metamorphic rocks. Most strata will allow some water movement

Transmission of groundwater

- A rock impervious to water at atmospheric pressure may be more permeable if fluid pressure is increased or, fluid becomes less viscous

- rate of water transmission depends on local hydraulic head → difference in height between source and measurement point

- vertical head pressure divided by distance over which the difference is measured → hydraulic gradient → driving force for groundwater movement

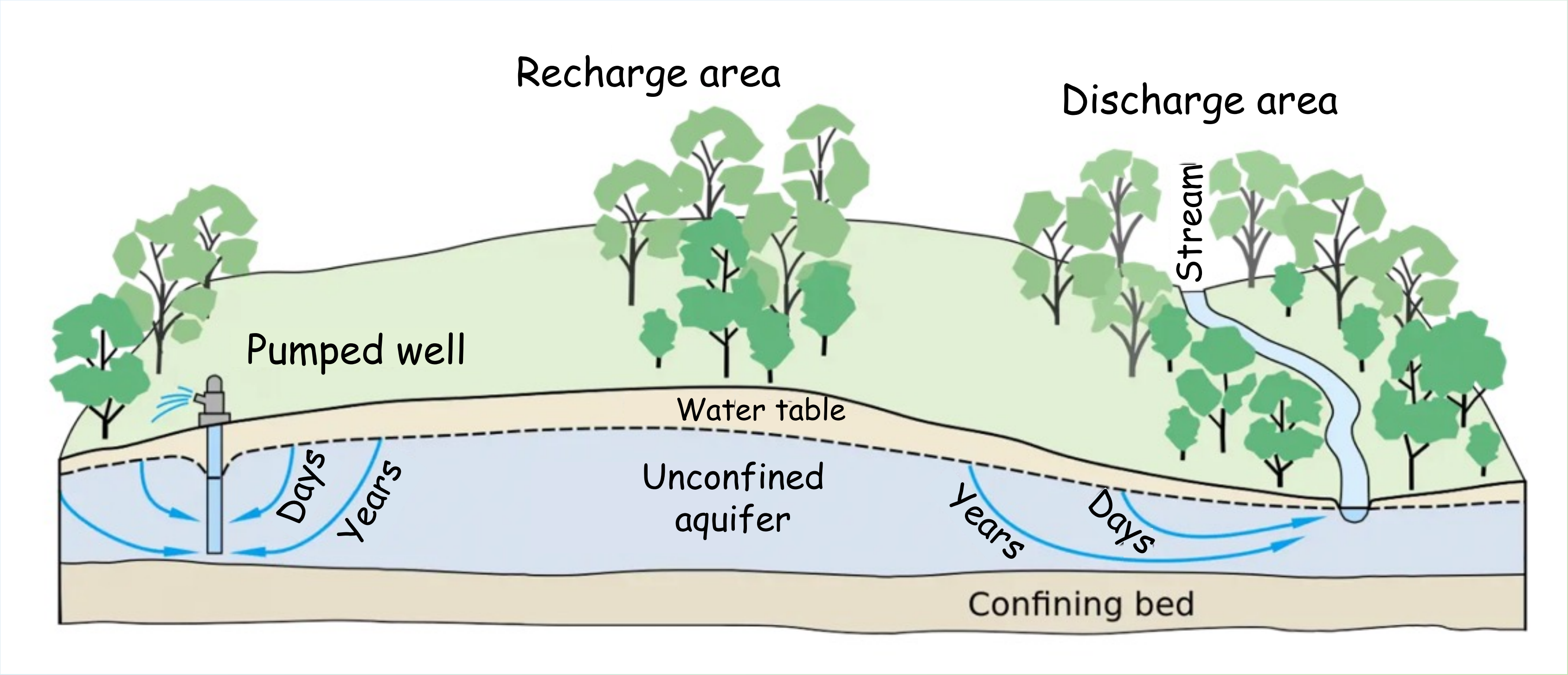
Groundwater flow

- Groundwater flows from recharge areas to discharge areas through pores and fractures in zone of saturation
- flows from high elevation to low elevation and from high pressure to low pressure
- flow dependent on hydraulic conductivity and hydraulic gradient
- greater the hydraulic conductivity and hydraulic gradient → more rapid the flow

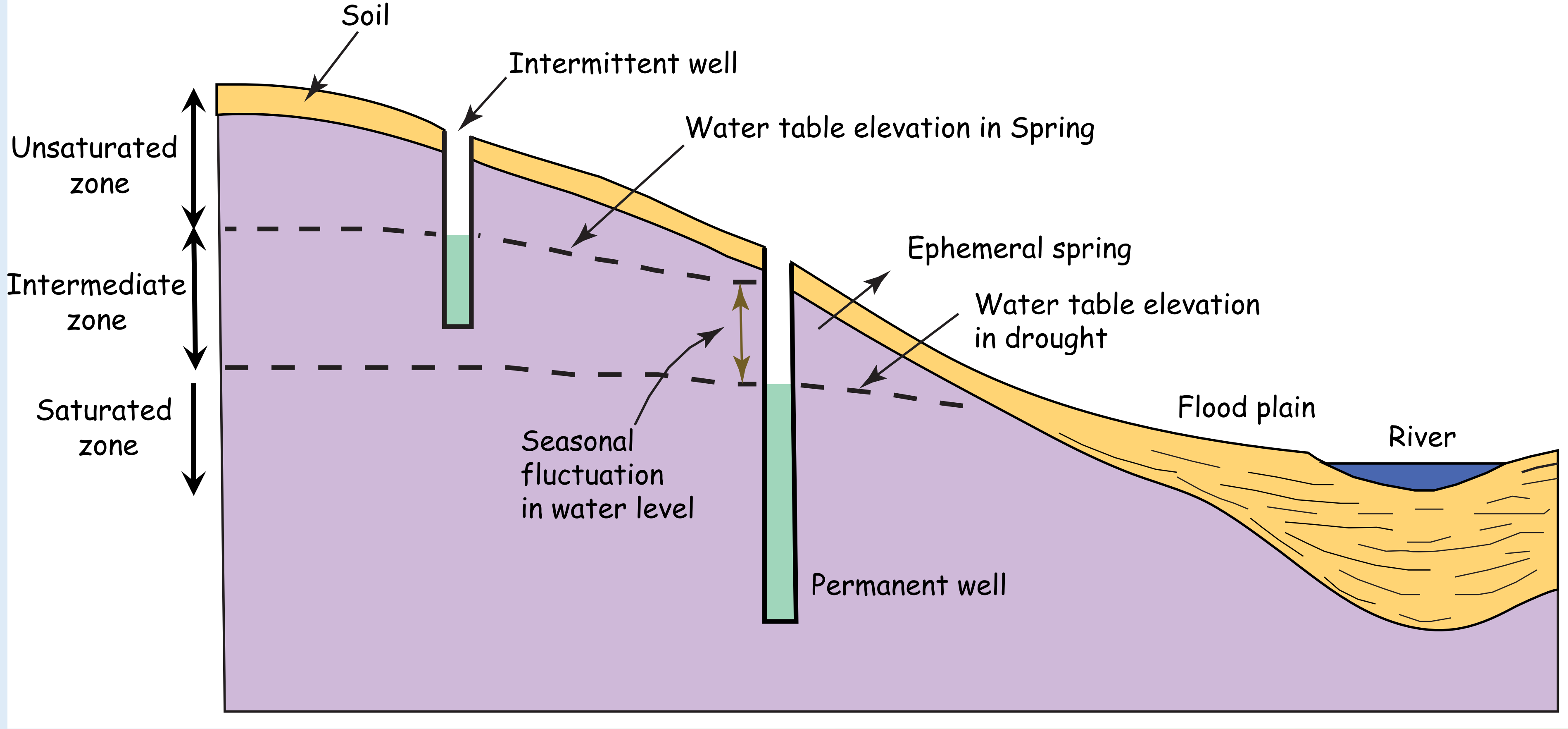
* Hydraulic gradient = elevation difference between the heads of two wells divided by their distance apart

Water table

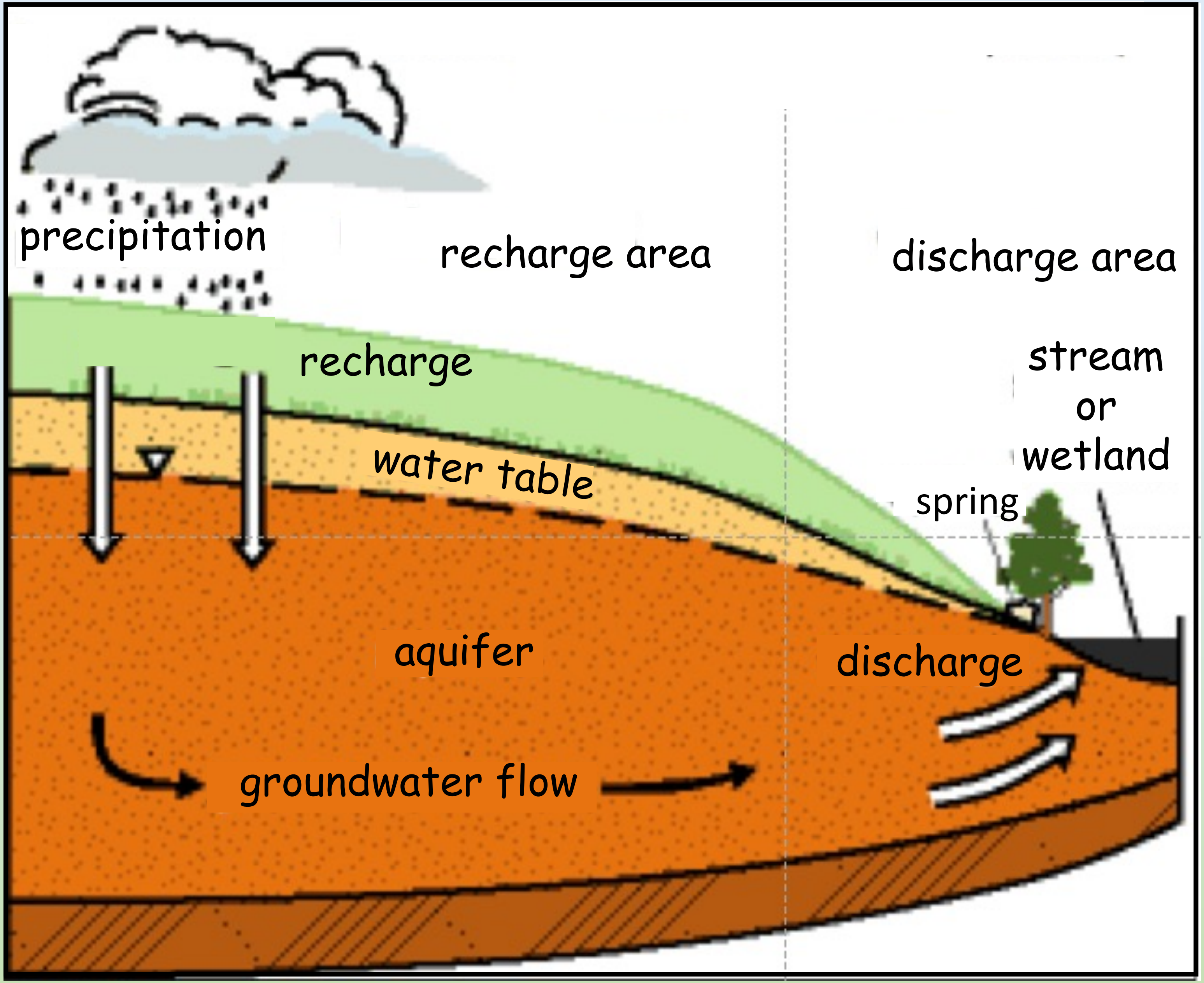
- Water table → upper surface of a zone of saturation
- water table may vary due to seasonal changes in precipitation and evapotranspiration
- water table typically slopes towards rivers that drain groundwater
- springs, rivers lakes and oases occur where water table reaches the surface



Water table fluctuation



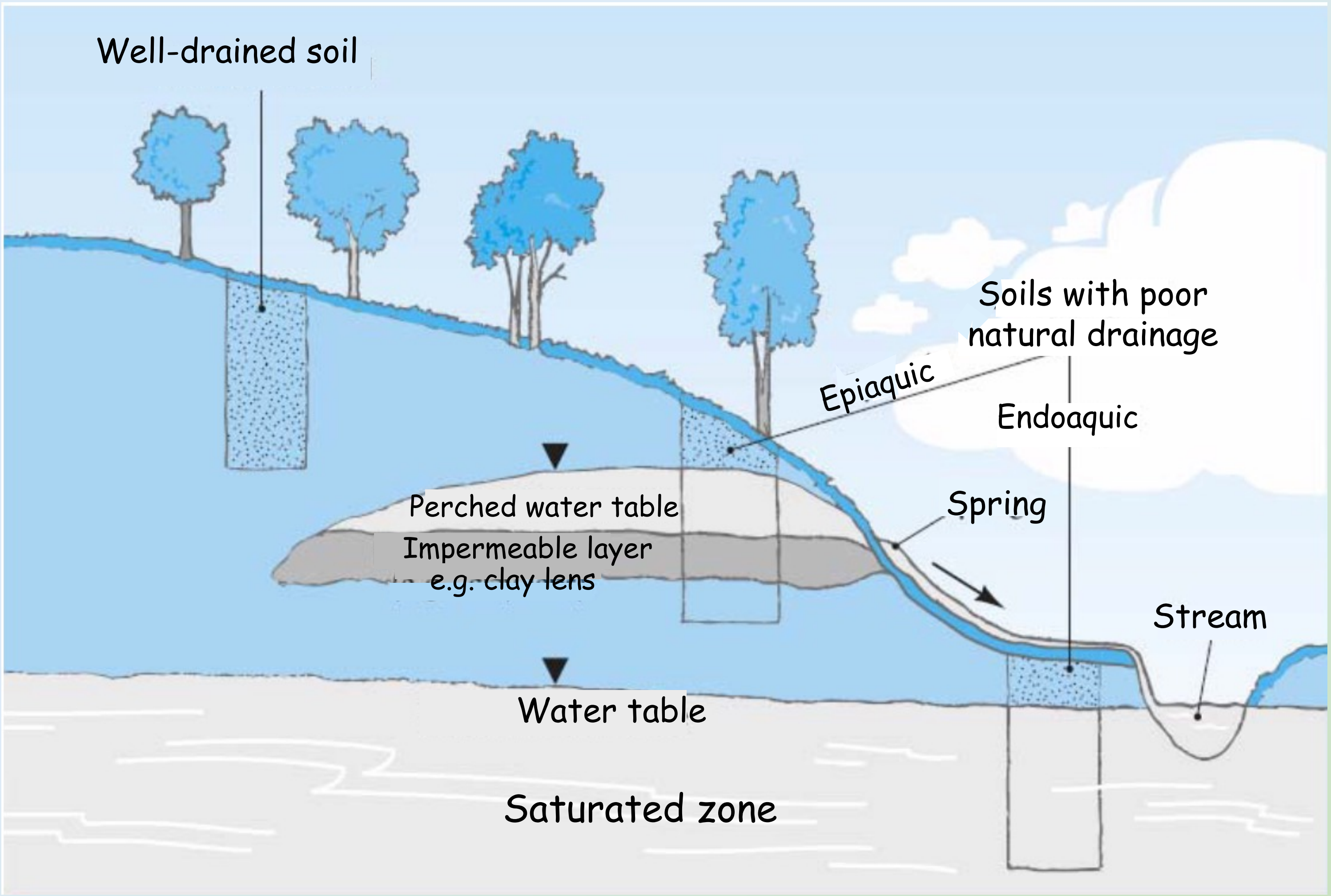
Groundwater discharge



Perched water table

- Locally occurring lenses or patches of impermeable rocks may result in the formation of a perched water table
- this saturated zone is immediately above the aquiclude and may be well above the regional water table
- the amount of water in a perched water table may be sensitive to local precipitation levels
- drilling into perched water table from above may deceive the driller by apparent depth of water table and shortage of water
- may require deeper drilling down to regional water table

Perched water table



Aquifers, aquitards, aquicludes

Aquifer – underground layer of water-bearing, permeable rock, rock fractures or unconsolidated materials from which usable volumes of water can be pumped

Aquitard – a layer of rock or clay layer that restricts the flow of water from one area to another

Aquiclude – any geological layer that absorbs water but does not transmit it → forms confining layer

Aquifers

- When an aquifer crops out at the surface → exhibits water table conditions
- formation above the water table is undersaturated but within it saturated areas may occur
- characteristics of aquifers vary with geology, structure of substrate and topography in which they occur
- frequently aquifers occur in alternating sequences of permeable and impermeable strata (unconfined/confined aquifers)
- more productive aquifers generally occur in sedimentary rocks

Confined/unconfined aquifers

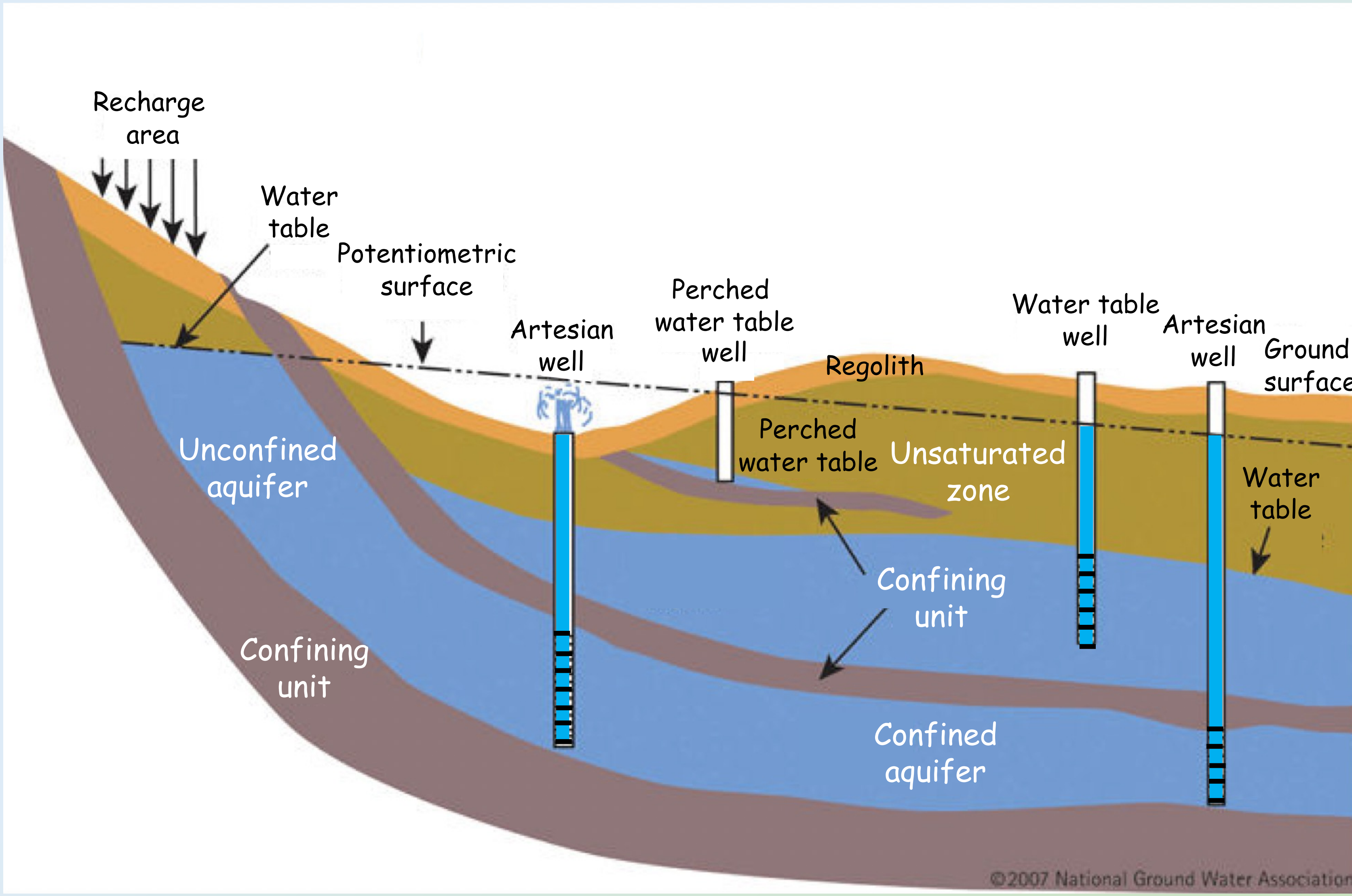
Unconfined aquifer

- → aquifer directly overlain by permeable rocks and soil
- unconfined aquifer may be recharged by infiltration over whole of the area overlain by that aquifer → nothing to stop downward flow from surface to water table

Confined aquifer

- → aquifer bounded above and below by aquicludes
- water in confined layer may be under considerable pressure → from adjacent rocks or lateral differences in elevation → can rise above height of aquifer in a bore

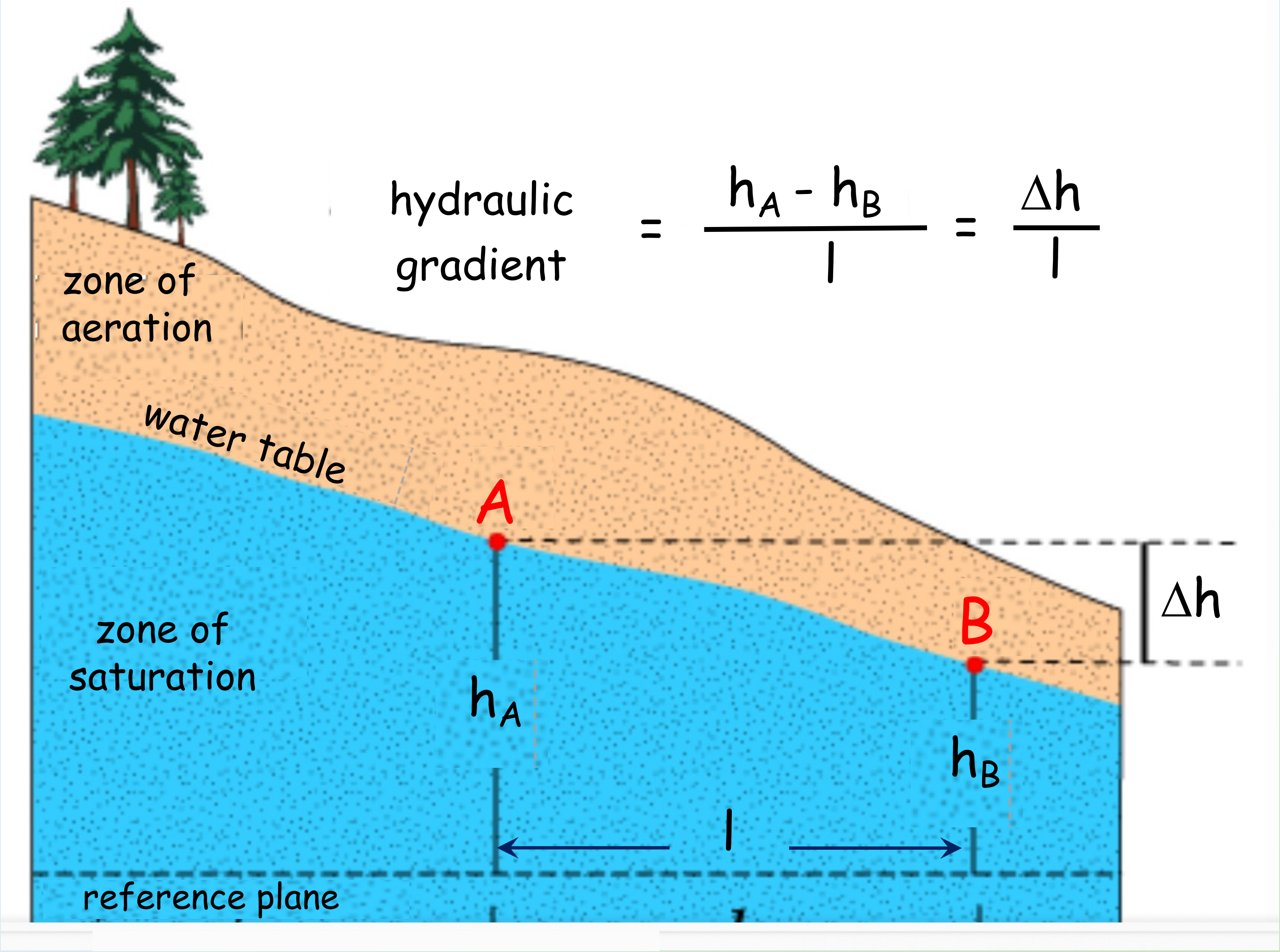
Confined/unconfined aquifers



Hydraulic head in groundwater

- The hydraulic head is an indicator of the total energy available to move water through an aquifer
- two forces drive flow:
  - (1) pressure gradient
  - (2) force of gravity
- total hydraulic head of a fluid is composed of pressure head and elevation head
- pressure head → equivalent gauge pressure of a column of water at its base
- distribution of hydraulic head through an aquifer determines where groundwater will flow

Hydraulic head



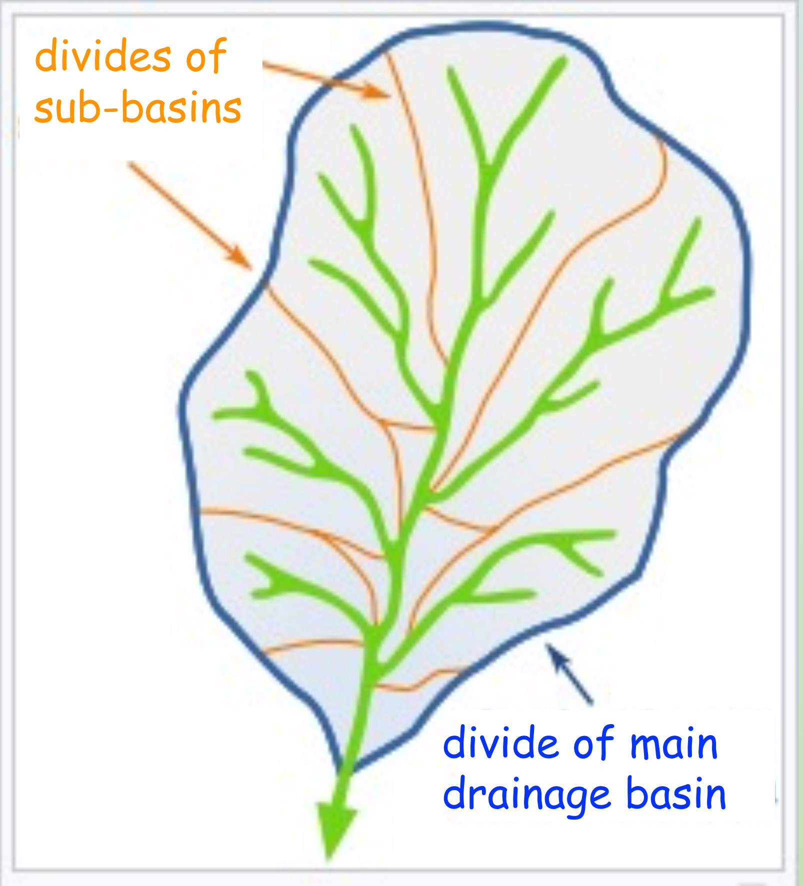
$$\text{hydraulic gradient} = \frac{h_A - h_B}{l} = \frac{\Delta h}{l}$$

h_A = pressure head at A h_B = pressure head at B Δh = elevation head

Drainage basins

- Drainage basin → area of land from which all flowing water converges on a point such as a river mouth
- drainage basins are separated from each other by drainage divides e.g. ridges, hills

Drainage basin of Mississippi River

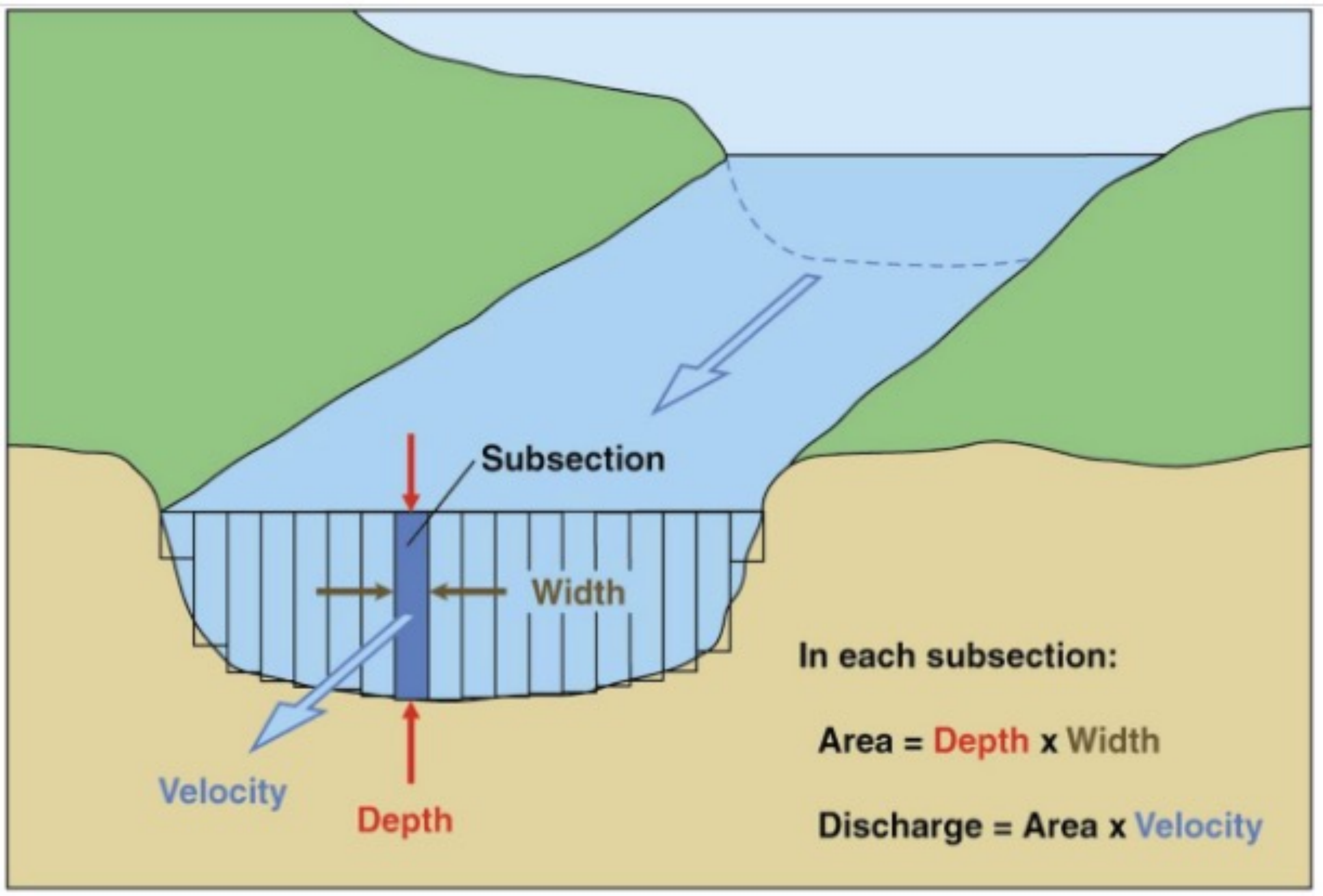


Stream features

- Stream → any body of flowing water confined in a channel
- streams draw their water from a drainage basin
- stream size is partly related to size of drainage basin → other factors → climate, vegetation and underlying geology
- size of stream described by its discharge → volume of water flowing past a given point over specified length of time
- discharge → product of channel cross-section x stream velocity
- discharge may vary from <30litres/sec (small creek) to millions of litres/sec (major river)

Stream discharge

Stream discharge is the volume of water that moves over a designated point over a fixed period of time

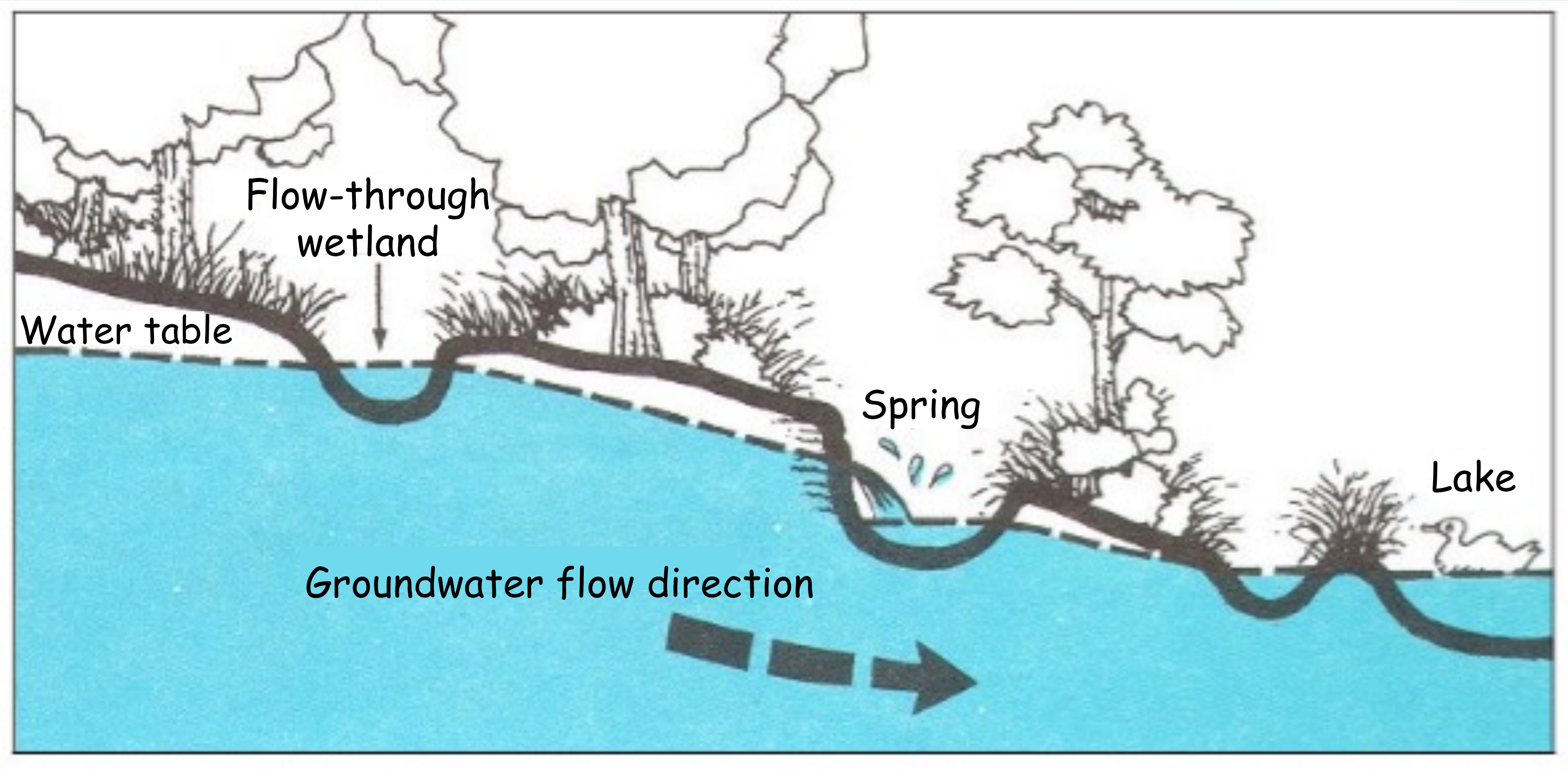


Groundwater interaction with surface

- Where water table level is higher than surface, water can enter streams, wetlands, form springs
- where water table level is lower than surface water level, a river can leak to recharge groundwater system (losing stream)
- groundwater can discharge into a stream in some places and leak into groundwater systems at others
- flow of water between surface water and aquifer is called seepage flux

Water table intersection with water table

Springs and wetlands exist where the water table intersects the land surface and water flows out of the ground



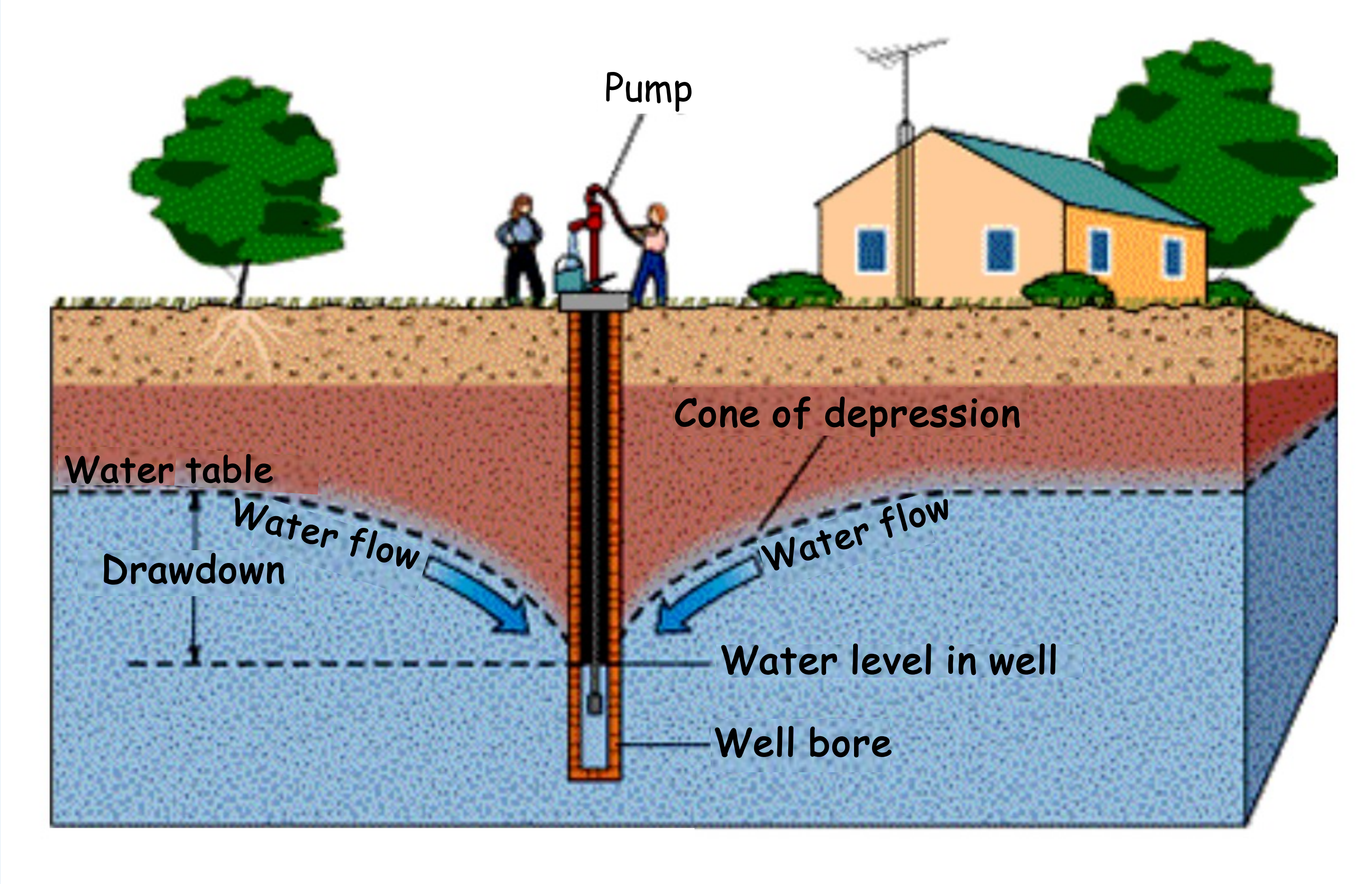
Consequences of groundwater withdrawal

- When water is pumped from an aquifer, the rate of replacement → generally slower than removal rate
- if groundwater withdrawal rates consistently exceed recharge rates → regional water table will drop
- in an unconfined aquifer → result is circular lowering around the wells → cone of depression
- groundwater pumped from wells in coastal regions → may cause saltwater intrusion

Cone of depression

- Cone of depression → a depression in the groundwater table or potentiometric surface with the shape of an inverted cone
- develops around a well from which water is drawn
- slopes become increasingly steep the closer they are to the well
- where there are many closely spaced wells → water in spaces between wells may be lowered → lowering water table

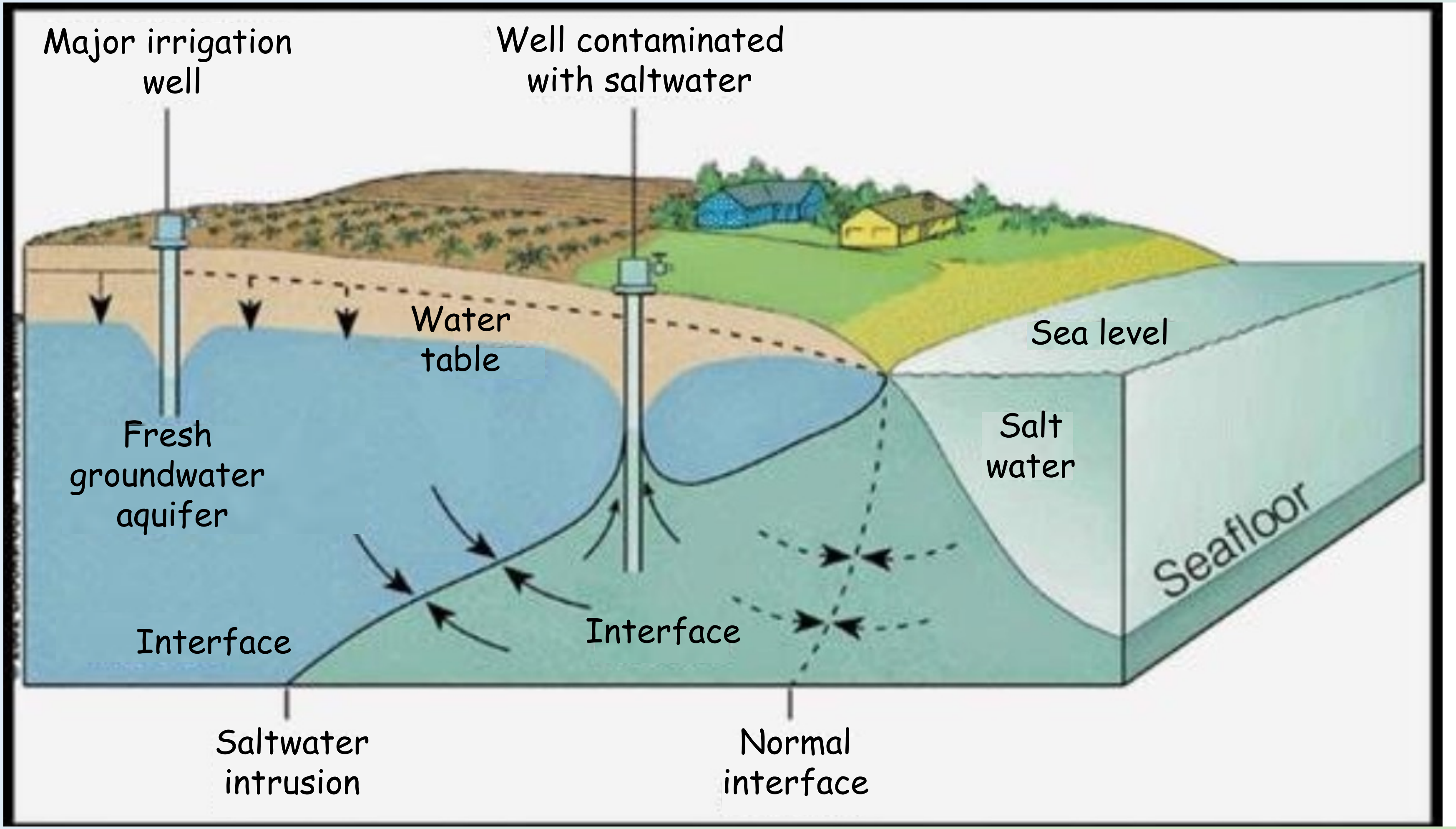
Cone of depression



Saltwater intrusion

- Saltwater intrusion → encroachment of saltwater into underground resources
- most common in coastal regions → freshwater replaced by inland movement of saltwater
- most common cause → pumping of freshwater from wells near the coast
- climate change can increase saltwater intrusion as sea level rises
- normally along coastal regions, freshwater flows downhill to the sea → prevents saltwater moving inland

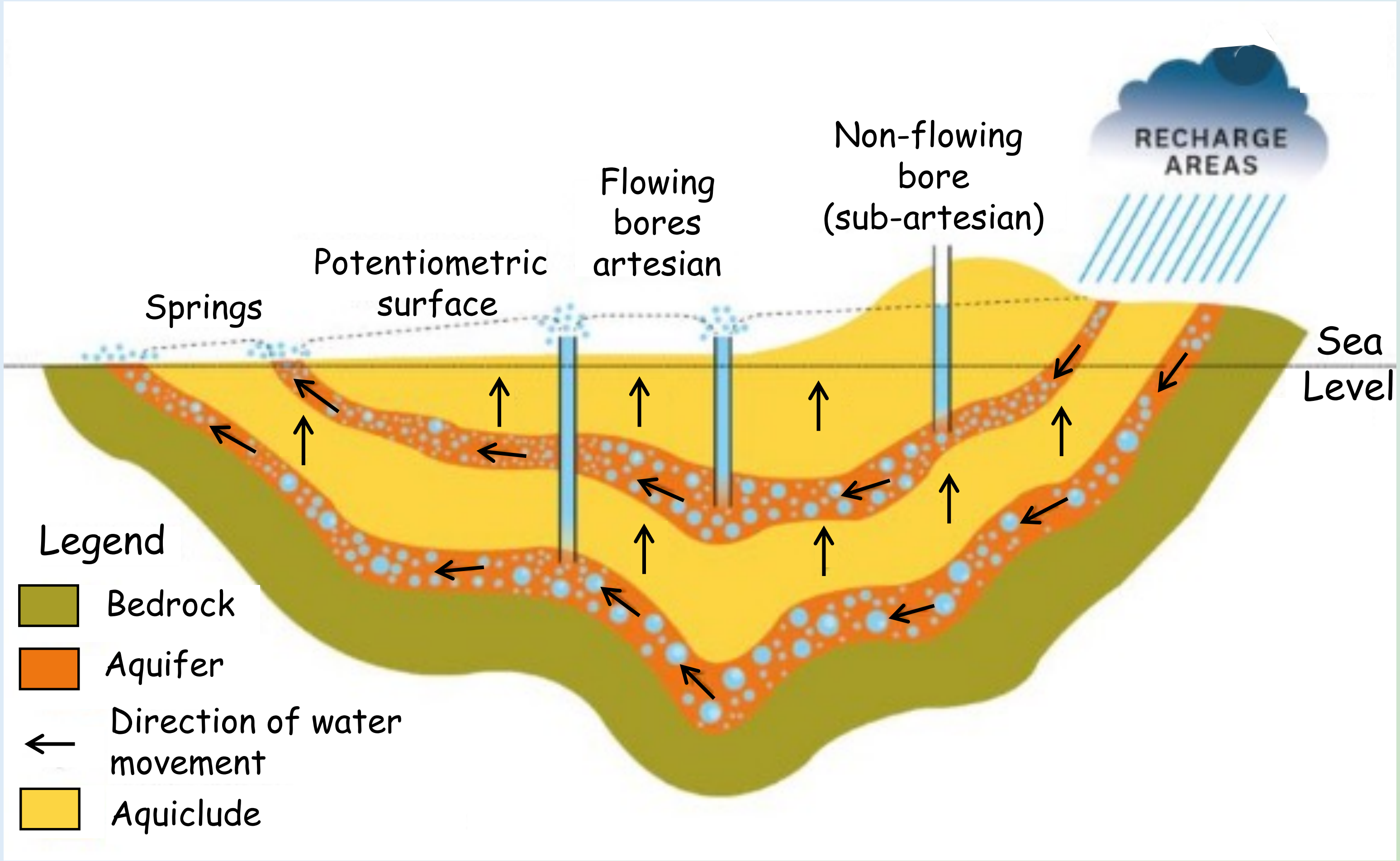
Saltwater intrusion



Artesian systems

- Artesian system → groundwater condition formed by aquifers in which water is confined above and below by poorly permeable rocks e.g. clay, shale
- water may be under pressure → if aquifer tapped by a well, water will rise above top of aquifer, may even flow onto land surface
- level to which water will rise in tightly cased wells → potentiometric surface
- if potentiometric surface is below land surface → water will not reach the the land surface
- if potentiometric surface is higher than land surface → water will emerge at land surface → artesian springs

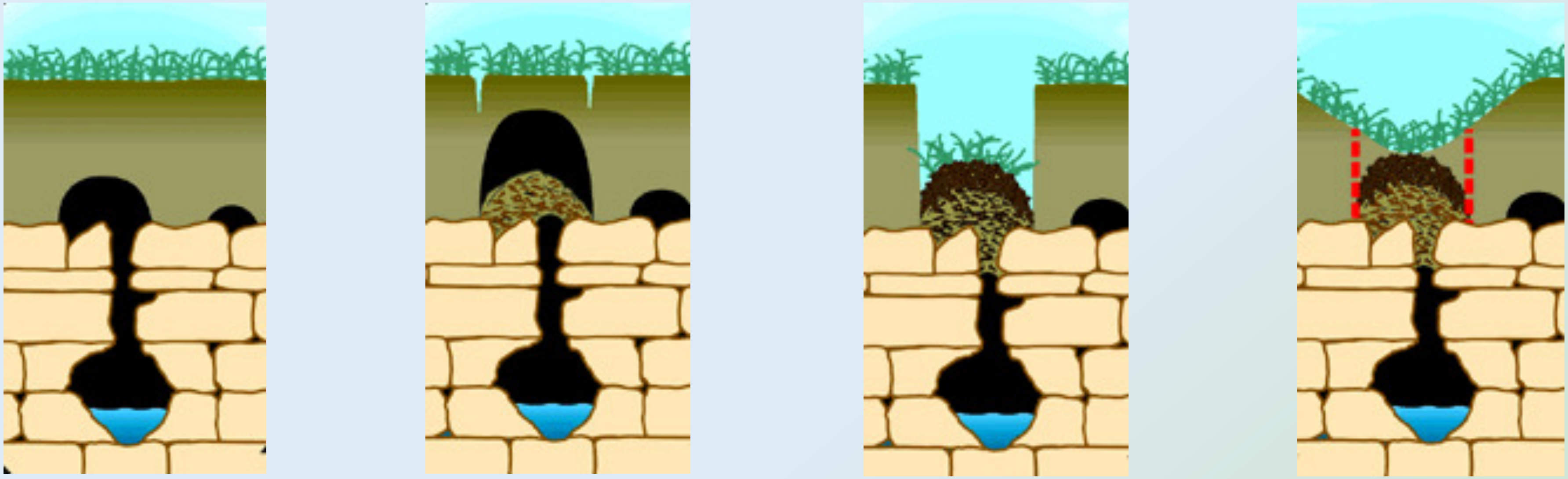
Artesian system



Sinkholes (dolines)

- Abundance of surface and near surface water → more water to dissolve soluble rocks
- most rocks are insoluble → a few rock types extremely soluble e.g. limestone
- over long periods of time, water may dissolve large volumes of limestone enlarging underground caverns → eroding support for overlying ground
- abrupt collapse at surface can produce voids called sinkholes
- collapse of sinkhole may result from drop in water table as result of drought or washing soil into caverns

Formation of sinkhole



1. 2. 3. 4.

1. Soil falls into crevice and is transported away by water
2. Further collapse of soil causes cracks to develop at surface
3. Soil roof collapses into developing sinkhole
4. Erosion by water smooths sharp edges → bowl shaped depression

Sinkhole

Sinkholes, West Virginia , USA

Sinkhole Guatemala City, 2010

Water quality

- Most water in the hydrosphere is in the salty oceans → almost all remainder in ice
- much of the water on the continents is not fresh
- even rainwater contains dissolved chemicals, especially in industrialised areas → air pollution
- once rain hits the ground, it reacts with soil, rocks and organic debris dissolving still more chemicals
- water quality therefore must be considered when evaluating water supplies

Measures of water quality

- most common measurement of dissolved chemicals → parts per million (ppm) → dilute solutions parts per billion (ppb)
- another way to express overall water quality → total dissolved salts (TDS) → sum of all dissolved solid chemicals in water
- composition of impurities also important. If main dissolved component is calcite → water may taste fine over 1000ppm → a few ppm Fe or S may make water taste bad
- some elements are toxic even at concentrations of 1ppb or less e.g. U, Rn
- pH that describes acidity and alkalinity of water is also important

Hard water

- In areas where water has passes through soluble rocks e.g. limestone → water described as "hard water"
- hard water contains substantial amounts of dissolved Ca and Mg
- when concentrations reach the range 80-100ppm, hardness can cause problems:
  (1) reacts with soap → prevents lathering → scum on laundered clothes
  (2) water high in dissolved salts may leave deposits in plumbing and appliances e.g. kettles, steam irons

Concentrations of some dissolved salts in rain , river water and seawater (ppm)

	Rainwater	Av. river water	Av. seawater
Silica (SiO_2)	-	13	6.4
calcium	1.41	15	400
sodium	0.42	6.3	10,500
potassium	-	2.3	380
magnesium	-	4.1	1,350
chloride	0.22	7.8	19,000
fluoride	-	-	1.3
sulphate	2.14	11	2,700
bicarbonate	-	58	142
nitrate	-	1	0.5

Surface water vs groundwater as supply

- In many areas → little or no surface water → substantial water deep underground e.g. Alice Springs
- tapping allows people to live and farm in uninhabitable areas
- stream flow varies seasonally, during dry season → water supply may be inadequate in some areas → reliance on groundwater
- lakes and rivers can supply surface water but may be polluted
- groundwater from saturated zone passes through rocks in aquifer filtering out some impurities (soil, bacteria)
- groundwater largest reservoir of fresh water → may be preferred as supplementary or sole water source